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Title: Preliminary Hyde Memorial State Park Modular Pumped Hydro Energy Storage Sizing Study

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Preliminary Hyde Memorial State Park Modular Pumped Hydro Energy Storage Sizing Study

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Introduction

Hyde Memorial State Park has lost grid supplied power and has been running on a diesel generator for some time now. The powerline that feeds the park is a state owned, 5 mile underground extension from the PNM service connection point. The line has decayed over the past 30 plus years and due to the location (much of it running under the road) the cost of repair and the logistics of closing the road are not good options. In June 2019 through a state contractor, the State of New Mexico Energy, Minerals and Natural Resources Department completed a renewable energy microgrid feasibility study to see if it was technically and economically feasible to operate the park without future grid power[1]. The study looked at solar plus battery storage and a propane generator as a possible option.

New Mexico State Parks Division has indicated their wish to move forward with the microgrid project which will now go out to one of the state's energy services performance contractors. The contractor will have to finalize the feasibility study and develop a complete list of construction costs. Given, the lack of long-term O&M data on the battery, as part of the next phase of the project the State of New Mexico Energy, Minerals and Natural Resources Department asked Los Alamos National Laboratory to preliminary examine the potential for pumped hydro as an alternative to batteries.

Preliminary Modular Pumped Hydro System Sizing

For purposes of this preliminary sizing study presented here, a modular pumped hydro energy storage facility is sized/specified from an energy management point of view. A high-level project cost is estimated at the end. The facility consists of a solar panel array, two separate penstock runs with upper and lower reservoir, and pump/turbine assembly as shown in Figure 1. Solar panels would be located above each reservoir as necessary in a dual-land-use approach. A backup propane generator is also sized as part of the full system considered to account for cloudy days and/or makeup needed at night. Specifications for inverters and transformers were not considered as part of this study, nor water chemistry control, maintenance issues, electrical switchgear, control systems, etc..

The design objective of the MPH energy storage system is for solar panels on average each day of each month to produce enough electricity to meet normal daytime park usage plus be able to fully charge the hydro energy storage system. The design specified in this report is the final result of an iterative process.

Table 1: Definition of Energy Storage Parameters to Form Baseline Design of MPH Facility Used in Study

Backup Generator	24 kW
Solar Panel Size	115 kW DC
Elevation Difference Between Reservoirs (i.e. Head)	100 ft
Efficiency of Energy Production (i.e. Turbine Mode)	82.45%
Efficiency of Pumping	72.75%
Power Rating (max per penstock)	25 kW
Maximum Energy Capable of being Released From Storage	240 kWh

(1) PSA 19-521-0300-0217, *Hyde Memorial State Park Microgrid Feasibility Study*, June 15, 2019, by Positive Energy Solar

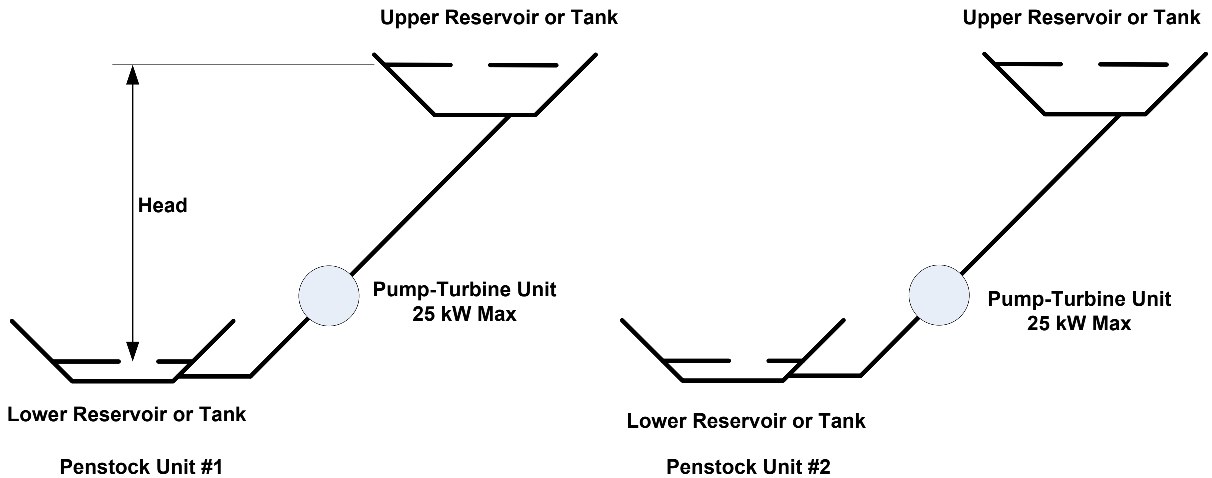


Figure 1: Schematic layout of two penstock runs operating in tandem as part of a complete MPH System. Solar panels and electrical transformer/switching are not shown for clarity. Each penstock run is rated to 25 kW maximum. Pumping is performed in parallel at 50 kW maximum power to shorten time of pumping during the solar day to charge system. Electricity is produced by running each penstock one after another in series at 25 kW maximum power to lengthen time of electrical production during the night.

Method of Approach and Results

To support the sizing nature of this study, results are presented in a table format. Table 2 presents the final results of this study. Table 3 is a summary of notes that explain the methodology used to create Table 2. Table 4 is a listing of PVWatts Performance Data Input referenced in table 3. Table 5 calculates out the energy needed for the baseline energy storage referenced in Table 3. Table 6 calculates how the full round trip efficiency is determined. Appendix ‘A’ presents general calculations used to support this sizing study.

Table 2: Hyde Memorial State Park Modular Pumped Hydro Energy Storage Sizing Study

Month	# of Days	Total Monthly Electrical Usage (kWh)	Average Daily Electrical Usage (kWh)	Constant Daily Power Usage (kW)	Daily Electrical Usage Distribution			Total Monthly Solar Production (kWh AC)	Average Daily Solar Production (kWh AC)	Energy to Charge Storage (kWh AC)	Energy Storage Available (kWh AC)	Discharge Duration (hrs)	Daily Energy Balance	
						Duration (hrs)	Electrical (kWh)						Make Up Needed During Night by Generator (kWh AC)	Extra Solar Production Available (kWh AC)
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Jan	31	11,200	361.3	15.05	Night	17	255.9	16,545	533.7	400	240	15.95	15.85	28.4
					Day	7	105.4							
Feb	28	11,800	421.4	17.56	Night	17	298.5	15,588	556.7	400	240	13.67	58.52	33.8
					Day	7	122.9							
Mar	31	11,800	380.6	15.86	Night	16	253.8	19,125	616.9	400	240	15.13	13.76	90.1
					Day	8	126.9							
Apr	30	11,000	366.7	15.28	Night	16	244.5	17,955	598.5	400	240	15.71	4.48	76.2
					Day	8	122.2							
May	31	10,000	322.6	13.44	Night	16	215.0	18,733	604.3	400	240	17.86	0	96.8
					Day	8	107.5							
Jun	30	9,000	300	12.5	Night	17	212.5	17,645	588.2	400	240	19.20	0	100.7
					Day	7	87.5							
Jul	31	8,000	258.1	10.75	Night	17	182.8	15,865	511.8	400	240	22.33	0	36.5
					Day	7	75.3							
Aug	31	7,000	225.8	9.41	Night	17	160.0	16,674	537.9	400	240	25.50	0	72.0
					Day	7	65.9							
Sep	30	7,000	233.3	9.72	Night	18	175.0	16,432	547.7	350	210	21.60	0	139.4
					Day	6	58.3							
Oct	31	8,000	258.1	10.75	Night	16	172.0	17,919	578.0	400	240	22.33	0	92.0
					Day	8	86.0							
Nov	30	8,400	280	11.67	Night	17	198.4	16,063	535.4	400	240	20.57	0	53.7
					Day	7	81.7							
Dec	31	9,800	316.1	13.17	Night	17	223.9	15,453	498.5	350	210	15.95	13.89	69.5
					Day	6	79.0							

Table 3: Engineering Notes Associated with Hyde Memorial State Park Modular Pumped Hydro Energy Storage Sizing Study

Column #	Variable Name		Notes
1	Month		
2	# of Days		
3	Total Monthly Electrical Usage (kWh)		Defined, taken from original report.
4	Average Daily Electrical Usage (kWh)		Computed by dividing column 3 by column 2.
5	Constant Daily Power Usage (kW)		Computed by dividing column 4 by 24 hrs. Based on results in this column for each month, sized backup generator at 24 kW. This power level is approximately 1.37 times the average for each month and is commercially available. Therefore, in the event of no or limited solar generation, generator could take on full peak of usage.
6	Daily Electrical Usage Distribution		Subdivide into night and day listing.
7		Duration (hrs)	Night is defined to be when solar generation falls below the 50-kW level from the estimated solar production web tool. Day is then defined as the difference between 24 hrs minus the night duration. This is a rough estimate and does not change much throughout the year because of the web tools factoring in of cloud cover.
8		Electrical (kWh)	Multiply corresponding night/day value in column 7 by column 5 to ensure conservation of energy. For each month, night and day usage adds up to column 4.
9	115 kW DC Solar Array	Total Monthly Solar Production (kWh AC)	Estimated from the PVWatts calculator from the National Renewable Energy Laboratory (http://pvwatts.nrel.gov/). Table 4 lists the input data to the calculator. The solar array size was specified to have a little extra solar available each month from column 14.
10		Average Daily Solar Production (kWh AC)	Calculated by dividing column 9 by column 2.
11	Energy to Charge Storage (kWh AC)		Calculated as (7 hrs)*(2*25 kW) + (2 hrs)*(2*12.5 kW), except where day column 7 < 7 hrs then use actual hrs of pumping available during day. Due to short durations available for charging during day hours, it is desirable to charge at faster rates during the day, and discharge at slower rates during the night. A hydro unit operates most efficiently near maximum pumping capacity. So specifying one large rated penstock that pumps at a high rate and then discharges at a slower rate is not desirable. Therefore two penstocks, each pumping at a maximum of 25 kW for 7 hrs are defined as the baseline energy storage capacity in this study since pumping for 7 hrs can take place most months. Each penstock is also defined to perform partial pumping for the equivalent of two hours a day at 12.5 kW. This accommodates average daily usage with one penstock operating at a time during the night in series, and two penstocks operating in parallel during the day. For those months where less than 7 hrs of pumping are available during the day, then less energy storage is available. Results for the baseline case to charge energy storage of 400 kWh are given in Table 4.
12	Energy Storage Available (kWh AC)		Calculated as column 11*(0.60). Due to inefficiencies in the hydro energy storage system, the full round trip efficiency is defined as 60%. A breakdown of how this was derived is given in Table 5.
13	Discharge Duration (hrs)		Calculated as column 12/column 5 with constant power discharge. If resulting value is greater than the definition of night duration, corresponding generator makeup will be zero because the night duration can be fully covered by the storage. When the discharge duration is less than the night duration, then back generation is required.
14	Daily Energy Balance	Make-Up Needed During Night by Generator (kWh AC)	Calculated as IF (column 8 night - column 12 < 0) THEN = 0, OTHERWISE = column 8 night - column 12. The objective is to use all solar produced during the day to meet daily usage and fully charge the energy storage. At night, use all of energy storage available, and then switch to backup generator. Larger energy storage would lower the duty cycle for backup generator required.
15		Extra Solar Production Available (kWh AC)	Calculated as column 10 - column 11 - column 8 day. Extra solar production during the day is available for general use to help offset unanticipated load.

Table 4: PVWatts Performance Data Input

Requested Location:	Hyde Memorial State Park, NM
Latitude (deg N):	35.73
Long (deg W):	105.82
Elevation (m):	2867.05
DC System Size (kW):	115
Module/Array Type:	Standard/Fixed (roof mount)
Array Tilt (deg):	30
Array Azimuth (deg):	180 (facing due south)
System Losses (%):	14.08
Inverter Efficiency (%):	96

Table 5: Baseline Energy Needed for Full Storage

	Duration (hrs)	Power In (kW)	Energy (kWh)
Max Pumping Flowrate	7	25	175
	7	25	175
			350
Partial Pumping Flowrate	2	12.5	25
	2	12.5	25
			50
		Subtotal	400

Table 6
Efficiency Determinations

	Pumping Mode	Turbine Mode	Round Trip
Transformer	0.97	0.97	----
Motor & Pump	0.75	0.85	----
	0.7275	0.8245	0.6

General Notes

Using conservation of energy applied to both maximum pumping and partial pumping for a height of 100 ft, estimate need 2.84 acre-ft of total water (see Appendix 'A'). Because of the location, excavation of reservoirs is not expected to be practical. Therefore, it is recommended to utilize a ModuTank Inc. type design (see attached). Note that four reservoirs/tanks will be needed due to parallel pumping. Water to fill each separate penstock system could come from a stream in the park or trucked in. Skid mounted Pumps as Turbine units, such as provided by KSB of Germany, would be utilized (see attached).

Estimated Project Cost

For consistency with the original feasibility study, a listing of the same items is provided below, with appropriate additions per this sizing study. This is a very rough estimate. Total project cost is comparable to the initial study.

Estimate Equipment Costs	**k$**
Penstock	30
Reservoirs/Tanks	350
Skid mounted Pumps as Turbines	200
Building/shed	10
Generator (24 kW)	10
Solar panels (133.4 KW to ensure 115 EOL capacity)	150
Supports & cabling	100
Install labor	150
Inverters	30
Safety Fence	40
Subcontracting	80
Permits/Engineering	80
Project Management	40
Design Labor	50
Transformer	10
Site work	100
Travel labor	30
Bonding	30
	1,490

Conclusion

A preliminary Modular Pumped Hydro energy storage system as presented in this report could be utilized as part of a micro grid for Hyde Memorial State Park in Santa Fe, New Mexico. Hydro has a long history of offering constant performance, decades of operational longevity, with minimal maintenance, making it a realistic choice for this application. Further, the application of pumped hydro offers ancillary opportunities such as a source of water at elevation for fire emergencies, the ability to integrate education (of the general public, secondary and collegiate students) into the operation of the facility, and provide a real world laboratory setting to conduct research on future energy innovations. These ancillary opportunities were beyond the scope of this report, but are essential to consider in future more refined studies because of the real world benefits they provide. While the size of the system specified is considered small by hydro standards, it would serve as an excellent prototype facility.

Appendix A: General Calculations Used in Support Of Sizing Study

Software Program used is MathCad 15.0 by PTC

Determine the amount of energy needed for Pumping:

$hrs\_p_{max} := 7$ hrs Number of hours a day pumping energy at max power.

$hrs\_p_{partial} := 2$ hrs Number of hours a day pumping energy at partial power.

For sizing purposes, define a constant electrical power input over the duration of pumping.

$P_{max} := 50.0$ Max pumping, kW. Two penstocks running in paralel operation.

$P_{partial} := 25$ Partial pumping, kW. Two penstocks running in paralel operation.

$E\_in_{max} := P_{max} \cdot hrs\_p_{max} = 350.0$ kWh, energy needed for pumping at max rate

$E\_in_{partial} := P_{partial} \cdot hrs\_p_{partial} = 50.0$ kWh, energy needed for pumping at partial rate

$E\_in := E\_in_{max} + E\_in_{partial} = 400$ Total energy required for pumping, kWh
(1 MWh = 10^3 kWh = 10^6 Wh)

Determine How much water is needed to perform this pumping:

$h := 100 \cdot .3048 = 30.48$ Define head at site, m

$\eta_p := .7275$ Efficiency of pumping process (decimal form).

Note: efficiencies are inclusive of turbine/pump, generator, transformer and penstock losses.

$\rho := 1000$ Density of water, kg/m^3

$g := 9.81$ Acceleration of gravity, m/sec^2

The following flowrate equation was derived from fundamental conservation of energy and mass principales for an incompressible fluid.

Max pumping rate:

$$q\_dot\_m3\_s\_max := \frac{\eta_p \cdot P_{max} \cdot 1000}{\rho \cdot g \cdot h} = 0.122$$ Corresponding avg pumping flowrate, m^3/sec

$q\_dot\_cfs\_max := q\_dot\_m3\_s\_max \cdot 35.315 = 4.296$ cfs

$volume\_m3\_max := q\_dot\_m3\_s\_max \cdot hrs\_p_{max} \cdot 3600 = 3.066 \times 10^3$ m3 Volume of water pumped

$volume\_acre\_ft\_max := \frac{volume\_m3\_max}{1233.5} = 2.49$ acre-ft

$volume\_gallons\_max := volume\_acre\_ft\_max \cdot 325851.427 = 8.098 \times 10^5$ gallons

Partial pumping rate:

$q\_dot\_m3\_s\_partial := \frac{\eta_p \cdot P_{partial} \cdot 1000}{\rho \cdot g \cdot h} = 0.061$ Corresponding avg pumping flowrate, m^3/sec

$q\_dot\_cfs\_partial := q\_dot\_m3\_s\_partial \cdot 35.315 = 2.148$ cfs

$volume\_m3\_partial := q\_dot\_m3\_s\_partial \cdot hrs\_p_{partial} \cdot 3600 = 437.947$ m^3 Volume of water pumped

$volume\_acre\_ft\_partial := \frac{volume\_m3\_partial}{1233.5} = 0.36$ acre-ft

$volume\_gallons\_partial := volume\_acre\_ft\_partial \cdot 325851.427 = 1.157 \times 10^5$ gallons

Total volume summations

$volume\_acre\_ft := volume\_acre\_ft\_max + volume\_acre\_ft\_partial = 2.84$ acre-ft

$volume\_m3 := volume\_m3\_max + volume\_m3\_partial = 3.504 \times 10^3$ m^3 Volume of water pumped

Given a certain volume of water at a certain elevation at a certain power level, determine how long discharge may take place:

$\eta_t := .8246$ Efficiency of turbine process

$V := volume\_m3 = 3503.6$ Total volume at elevation, m3

$P := 17.56$ Average constant power rate during discharge, kW

$duration := \frac{V \cdot (\eta_t \cdot \rho \cdot g \cdot h)}{P \cdot 1000} = 49194.246$ Duration of dischaarge at constant power, sec. Two penstocks operate in series, one after another.

$duration\_hr := \frac{duration}{3600} = 13.665$ hrs

Determine how much energy out of facility is available to use:

$\eta_{overall} := \eta_p \cdot \eta_t = 0.6$ Overall roundtrip efficiency (decimal form)

The overall roundtrip efficiency is defined as the ratio of energy produced to energy pumped (equivalent to the ratio of energy out to energy in).

In present case, the energy in to the MPH plant is the energy used to pump the water uphill (calculated above):

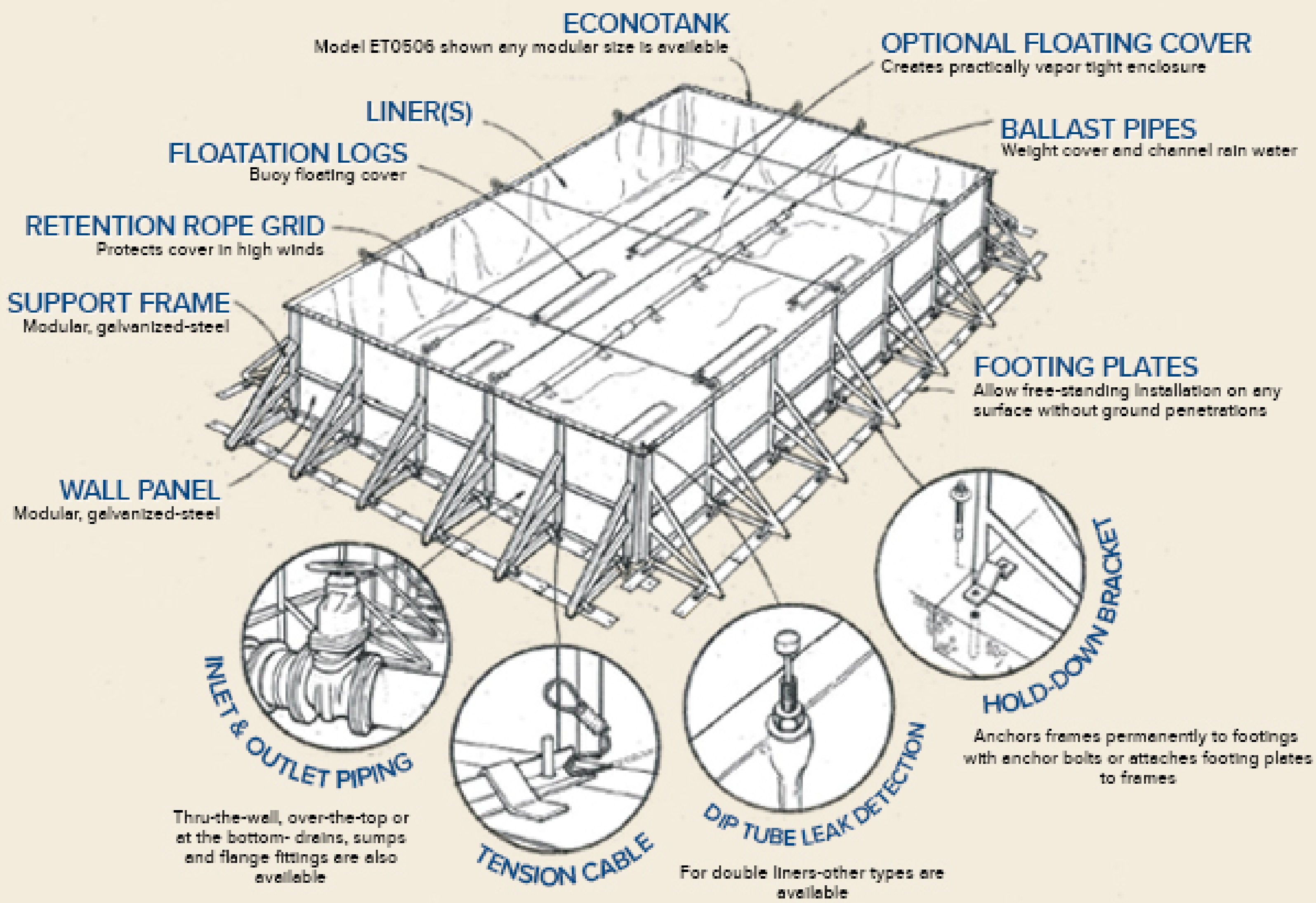
$E\_in = 400.00$ Energy in to MPH plant, kWh

Therefore:

$E\_out := \eta_{overall} \cdot E\_in = 240.0$ Energy out of MPH plant, kWh

This is the amount of energy (i.e. electricity) that is able to be utilized.

EconoTank™ Overview



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Pumps used as Turbines.
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KSB

Pumps used as Turbines: Worthwhile. Efficient. Economical.

As one of the world's leading manufacturers of pumps, valves and systems, KSB has offered efficient and reliable fluids transport solutions for more than 140 years. With cutting edge pump and valve technology, we transport and control almost every kind of fluid. KSB's package comprises consulting, planning, selection and commissioning of equipment, as well as all required services from a single source.

Rising energy prices and finite energy resources call for alternatives and solutions that help save money, for example, centrifugal pumps running in reverse. Pumps used as turbines, or PaT for short, are KSB's answer to conventional water turbines. They offer huge advantages such as low investment outlay as well as low service and maintenance costs combined with tried and tested technology.

A pump used as a turbine (PaT) can deploy the hydropower potential extremely efficiently and economically with straightforward technical means. PaT are suitable for applications where pressure differences are to be reduced or where the head and flow rate of an installation can be exploited. The power generated can either be used by the operator for internal purposes or fed into the public grid. Thanks to their low investment costs our PaT solutions pay for themselves after a very short time.

Applications for pumps used as turbines:

- Drinking water supply systems
  - Pressure reduction between elevated and low level tank
  - Pressure control in closed-loop systems
  - Reduction of pressure head
- Residual water utilisation in
  - Small hydropower stations
  - Pumped storage plants
  - Barrages
- Retrofitting of small hydropower systems
  - If customised Kaplan turbines are too expensive
  - For heads starting from 10 metres
- Industrial applications
  - Pressure control in cooling circuits
  - Reduction of process water pressure

The benefits of a PaT speak for themselves.

- Because of low investment costs and high energy prices, the payback period of PaT systems often is no more than three years.
- Good performance at best efficiency point makes the system very economical to operate.
- Low service and maintenance costs keep the life cycle costs down.
- Adjustment to fluctuating water levels is possible by splitting the total volume among several pumps of different sizes.
- With a minimum of control, as many modules can be operated economically as the system capacity requires.
- Pumps are decidedly easier to service and handle than “real” turbines.

The economic efficiency of a PaT system is convincing.

We design and select the most economically efficient PaT system for almost any combination and variation of flow rate and head. Systems can be adjusted to the desired operating point by the following means:

Fixed speed
If the system is operated at fixed speed, we select the right PaT for a given flow rate and head. For other operating conditions, additional throttling elements or a bypass will be provided. The PaT system is technically simple, easy to handle and, most of all, extremely cost-effective.

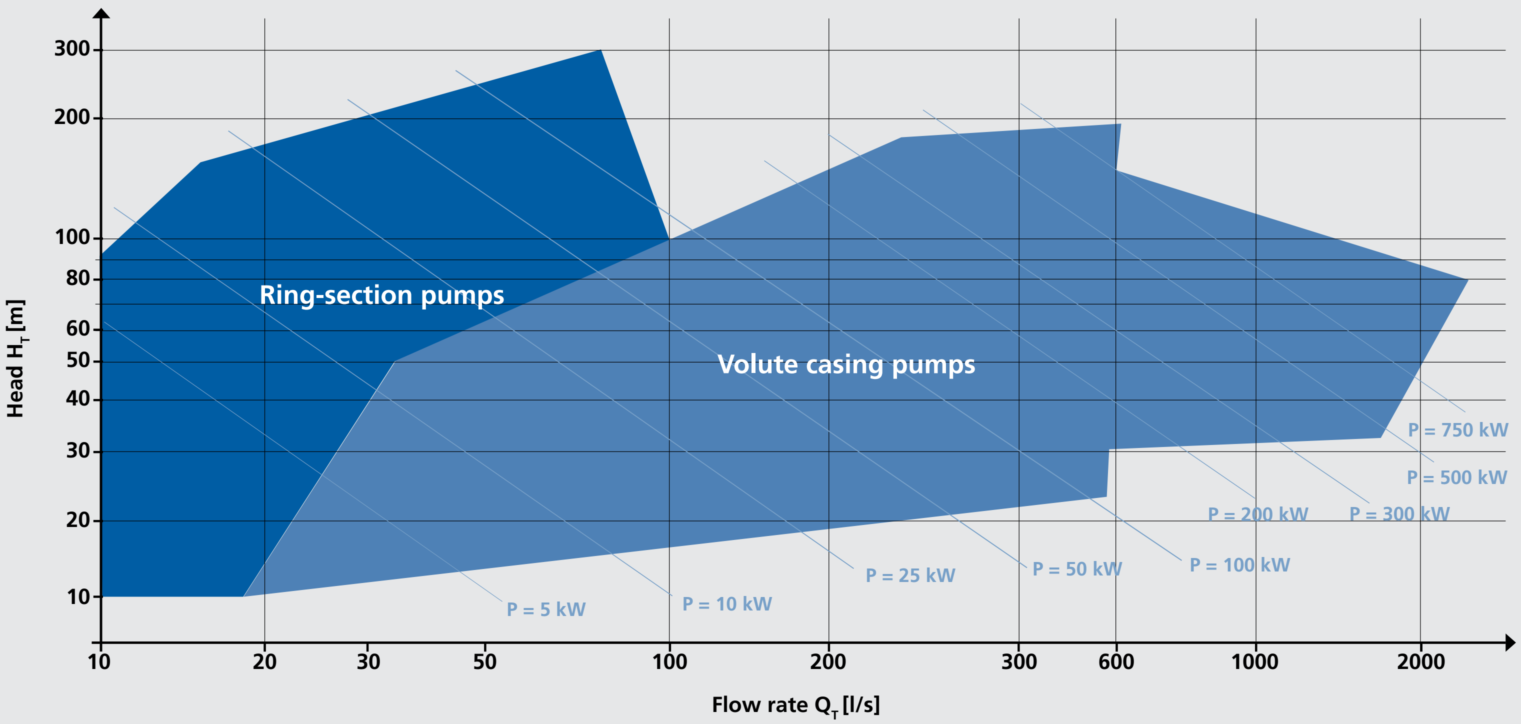
Variable speed
Variable speeds allow the operator to fully utilise the existing energy potential without the need for additional throttling. An energy recovery-type frequency inverter can also be used.

PaT operated in parallel
Cascade operation is an excellent way to take full advantage of the energy potential – in particular, if the flow rate varies. It involves splitting the total flow among several PaT running in parallel at fixed speed.

Direct connection to a work machine
The turbine either serves to drive the work machine directly or to reduce the load of the prime mover via a common shaft.

Omega volute casing pumps by KSB run in reverse

Hydraulic selection chart for pumps used as turbines (at a speed of 1.500 min^{-1})



MVE Vyšni Lhoty, Czech Republic

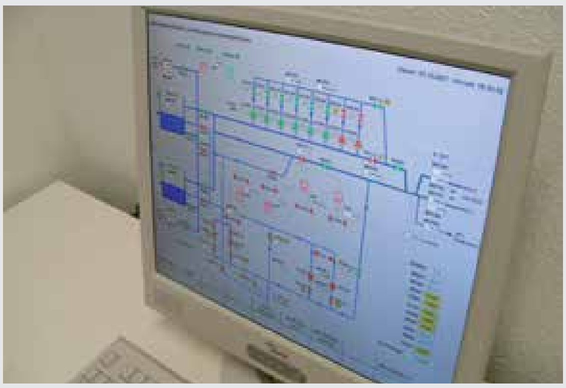
Vyšni Lhoty power station uses the hydropower potential of the water supplied from the dam. Three Etanorm pumps running in reverse and operated in parallel, with 90 kW, 110 kW and 132 kW respectively, jointly generate around 1,000 MW output per hour. The investment had paid for itself after a mere two years.

Thanks to the trouble-free operation of the system, the operator will continue to achieve high energy savings in the future.

Customer:
SmVak Ostrava

Scope of supply:
1x Etanorm G 150-400
1x Etanorm RG 200-400
1x Etanorm RG 300-500

Commissioned:
02/2008



Electricity recovery system in Breech, Germany

Eight pumps are employed in the Breech electricity recovery system to not only reduce the pipeline pressure but also to generate electricity as they are simultaneously used as turbines for energy recovery. The pumps used are standard products which run in reverse and are operated in parallel (they cut in or stop operating in accordance with the flow rate).
The expected energy yield is 300 kW with the system run at best efficiency point, and the electricity gained is fed into the grid of the local energy provider by the Regional Water Association. In this way, the system pays for itself after approximately three years.

Customer:
Regional Water Association, Stuttgart, Germany

Scope of supply:
8 Etanorm M 150-315 pump units

Commissioned:
12/2005 – 01/2006

"Tubishof" energy recovery system, Luxembourg

The Tubishof energy recovery system of the Luxembourg Municipal Waterworks had a Multitec 100 pump installed in 2010. In collaboration with the local service partner EFG, KSB supplied not only the pump used as a turbine (PaT), a generator and various accessories, but also the electrical control cabinet. The control cabinet serves two purposes: to feed electricity into the public grid and to control the valves during the start and stop procedure. It is linked to the owner-supplied process control system via Profibus. At a flow rate of approximately 28 l/s, the PaT reduces the pressure by approx. 11.5 bar and feeds approx. 200,000 kWh into the grid per annum.

End user / investor:
Luxembourg Municipal Waterworks

Scope of supply:
Multitec 100/5-7.1, control cabinet

Commissioned:
03/2010

Municipal Services, Kufstein, Austria

As part of a modernisation project, the new hydropower station of the Theaterhütte elevated distributing tank was put into operation in the spring of 2006 in cooperation with KSB Austria. The electricity generated – around 180,000 kWh per year – is fed into the low-voltage system of Kufstein Municipal Services. The so-called green electricity law makes the new small hydropower station also highly profitable from an economic viewpoint. And since the existing building accommodating the distributing tank could be used as a power house, building costs could be reduced to a minimum. The total capital outlay came to ¤ 90,000.

Customer:
Kufstein Municipal Services

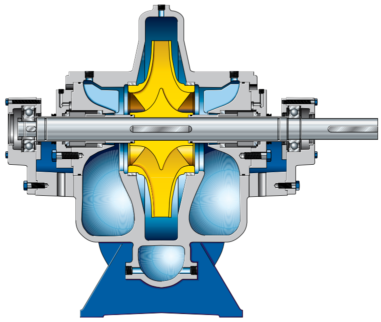
Scope of supply:
1 x Etanorm M 80-250

Commissioned:
01/2005

Omega Axially split volute casing pump

Single-stage, axially split volute casing pump for horizontal or vertical installation with double-entry radial impeller, mating flanges to DIN, ISO, BS or ANSI.

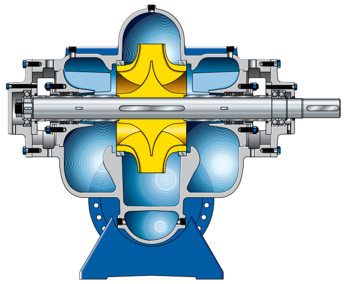
*Q_{max}: 4,000 m³/h
*H_{max}: 250 m



RDLO Axially split volute casing pump

Single-stage, axially split volute casing pump for horizontal or vertical installation with double-entry radial impeller, mating flanges to DIN, ISO, BS or ANSI.

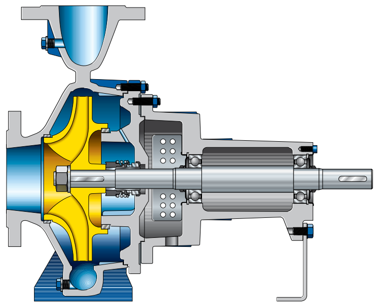
**Q_{max}: approx. 5,000 m³/h
**H_{max}: 250 m



Etanorm/Etanorm-R Standardised pump

Horizontal, long-coupled, single-stage volute casing pump (pump sizes > 125 with two stages) in back pull-out design. Replaceable shaft sleeves / shaft protecting sleeves and casing wear rings.

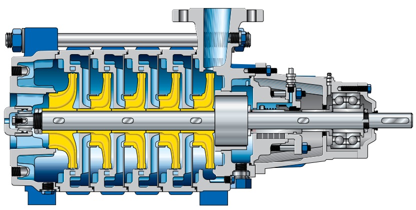
*Q_{max}: 660 m³/h
*H_{max}: 160 m



Multitec High-pressure ring-section pump

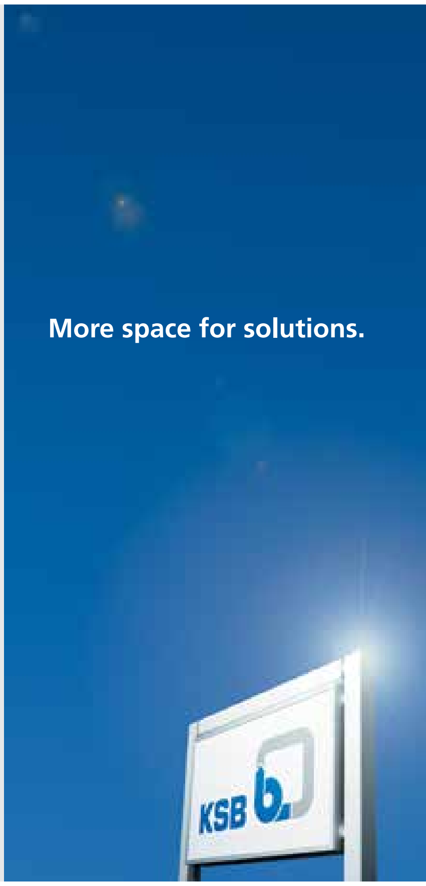
Multistage horizontal or vertical centrifugal pump in ring-section design, long-coupled and close-coupled versions, with axial or radial suction nozzle, cast radial impellers.

*Q_{max}: 700 m³/h
*H_{max}: 630 m



* Operating limits at a speed of 1.500 min⁻¹
** Operating limits at a speed of 1.000 min⁻¹

Your local KSB representative:



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